

Cardiovascular response and safety of virtual reality exergame in acute geriatric ward

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ABSTRACT

BACKGROUND Exergames have been proven to effectively improve physical function, particularly in the elderly. Although, older adults were once considered a low-tech population, tailored exergame interventions have proven beneficial. However, utilizing virtual reality (VR) in group presents challenges related to both cognitive acceptance and cardiovascular tolerance. This study aimed to evaluate cardiovascular responses, safety, and exercise intensity or VR-based exergaming in an acute care setting and to explore what to consider when giving exergames to subjects with high comorbidity.

METHODS This pre-post study used the Oculus Meta Quest 2® platform in 32 elderly participants. Each completed a single exergame session. Pre- and post-session assessments included measurements of heart rate (HR), systolic blood pressure (SBP), and diastolic blood pressure (DBP). Cardiopulmonary sentinel signs were monitored thoroughly.

RESULTS Post-exergame HR was significantly higher than baseline (82 [18] beats per minute [bpm] versus 79 [17] bpm; $p = 0.004$; mean difference: 4 [8] bpm). Blood pressure decreased slightly, but not significantly (SBP: -1 [14] mmHg, $p = 0.837$; DBP: 0 [12] mmHg, $p = 0.829$). Most participants experienced light-intensity activities ($n = 26$, 81%). No sentinel events occurred.

CONCLUSIONS A single session of VR exergaming safely increased HR above baseline in elderly participants, with activity predominantly classified as light intensity. Further studies should explore the determinants of exergame intensity to optimize prescriptions and tailoring.

KEYWORDS elderly, exergames, heart rate, virtual reality

Hospitalization often leads to deconditioning syndrome, contributing to hospital-acquired disability, particularly among older adults.¹ Therefore, early mobilization in acute care settings is essential.²

Various strategies, including virtual reality (VR), have been developed to facilitate mobilization in these environments.^{3,4} VR may help overcome mobilization barriers such as delirium, anxiety, depression, and

fatigue.^{5,6} Additionally, VR may enhance medical and rehabilitation outcomes, reduce length of hospital stay, and lower healthcare costs.^{3,4,7} These benefits may stem from the ability of VR to simulate familiar daily environments within clinical settings, thereby improving mood and patient compliance.^{2,8} When combined with exercise (exergaming), VR serves as an innovative approach to promoting early mobilization in acute care.

Clinical studies investigating exergames in acute settings remain limited because exergames are primarily designed to promote physical activity. Physical activity encompasses any bodily movement that increases energy expenditure, whereas exercise is a structured and purposeful subset designed to improve physical fitness. VR-based exergames offer potential benefits by enhancing engagement, motivation, and accessibility, thereby supporting healthier lifestyles. Physical activities can be structured in a repetitive and goal-oriented manner to improve or maintain physical fitness. However, achieving this requires specific goals, careful content selection, and appropriate intensity settings to transform physical activity into exercise.⁹ This flexibility enables the customization or development of exergames for older adults, such as the VRAGMENT module used in this study.

VRAGMENT, a novel Indonesian VR platform, has potential applicability across diverse clinical settings. However, implementing exergames in older adults, particularly in acute care settings, presents unique challenges related to cardiovascular tolerance. Therefore, this study aimed to assess the cardiovascular responses, safety of exergames in older patients, and exercise intensity during a single exergame session conducted in an acute geriatric ward, and to identify key considerations when administering exergames to patients with high comorbidity burdens.

METHODS

Study design

This study employed a prospective single-group pre-post (before-after) design with a prespecified analysis plan, using the Oculus Meta Quest 2[®] platform (Meta Platforms, Inc., USA) to run the VRAGMENT module. A total of 32 participants were screened for eligibility by the daily ward clinical team, and enrollment was conducted using consecutive

sampling. This study was powered at $1-\gamma = 0.8$ with type I error $\alpha = 0.05$. The minimum mean differences of pre-post intervention were defined according to previous studies.^{10,11} This study was approved by the Health Research Ethics Committee of the Faculty of Medicine, Universitas Indonesia, Cipto Mangunkusumo Hospital (No: KET-261/UN2.F1/ETIK/PPM.00.02/2024).

Participants and setting

This study was conducted between March and June 2024 at the Cipto Mangunkusumo Hospital, a tertiary care hospital and national referral center, in its integrated geriatric acute ward. The ward serves older adults with geriatric syndrome under acute conditions. During the acute phase, all rehabilitation programs were conducted under strict clinical supervision, with continuous monitoring of vital signs to ensure patient safety. Patients were eligible if they were deemed medically stable (alert and cooperative as in mobilization management level I to IV) for noninvasive sensory interventions by the attending physician. To reduce bias, inclusion was limited to individuals aged 60–89 years with a mobilization capacity level ≥ 3 and the ability to communicate. Each patient underwent a comprehensive geriatric assessment and individualized discharge planning within 72 hours of admission. A supervised bedside session was conducted during the index hospitalization, with vitals measured immediately before and after the session. Interdisciplinary management focuses on advanced clinical improvement, early mobilization, and psychosocial adjustment to improve patient prognosis and quality of life. VRAGMENT was designed for participants with cognitive impairments and could be used by those with mild-to-severe cognitive disorders (classified based on the Montreal Cognitive Assessment-Indonesian version), provided that they were able to engage in reciprocal communication. Patients were excluded if they had any contraindications (moderate-to-severe depression, VR-sickness, total deafness, low vision ability, and numeric rating scale [NRS] of pain higher than 3) to physical activity according to the hospital's clinical practice guidelines.¹² Written informed consent was obtained from all participants or their legal representatives (individuals who provides consent on behalf of an adult who lacks mental capacity to make decisions for themselves).

Equipment

The Oculus Meta Quest 2® VR hardware was used with a gaming laptop (HP Omen®; HP Inc., USA) connected via cable for real-time feedback and operator guidance. Handheld controllers were used to interact with virtual objects.

Procedures

Before the intervention, patients underwent a familiarization session that included an introduction to the VR hardware, a preview of the virtual environment, and a step-by-step explanation of the gameplay. Each session began with a baseline assessment of vital signs (heart rate [HR], blood pressure [BP], systolic blood pressure [SBP], diastolic blood pressure [DBP], and rating of perceived exertion [RPE]) before and after the exergames. Patients received instructions on using the headset and controllers and then engaged in the VR activity at the lowest difficulty level. Throughout the session, patient responses and gameplay duration were closely monitored under real-time operator guidance, with a target session duration of 10 min.

The intensity level was increased only if the patient demonstrated the ability to complete all gameplay components independently. Family members and the operator were allowed to provide feedback to support the patient's engagement. Vital signs and RPE were reassessed during and after the session, and any symptoms of VR-induced discomfort (e.g., dizziness, nausea, or VR sickness) were documented. Training intensity and supervision were then adjusted based on the patients' clinical status.

Clear termination criteria were applied to ensure patient safety. Sessions were immediately discontinued if any of the following occurred: complaints of headache, dizziness, chest pain or pressure, shortness of breath, cold sweats, palpitations, nausea, or significant musculoskeletal pain (NRS >3); an SBP decrease >20 mmHg; a rise in SBP >200 mmHg or DBP >115 mmHg; patient request to stop; or session duration exceeding 10 min.

The VRAGMENT module simulates grocery shopping, requiring participants to search for listed items by scanning the virtual environment, reaching towards shelves, and picking and placing groceries into a basket using the controller. All sessions were conducted in a seated position based on clinical judgment and participant preference, although the VRAGMENT can also be played while standing.

Designed as an aerobic exergame to address fatigue in hospitalized older adults,¹ the module emphasizes repetitive biceps and triceps contractions with low-intensity, high-repetition movements in large muscle groups. All exergame sessions were supervised by a trained physician familiar with the VRAGMENT module and certified in the acute ward safety mobilization protocol. The unit of assignment and analysis was the individual patient. This was a single-group intervention study without randomization or allocation. Participant and provider blinding was not feasible; however, the outcome assessor was blinded to the pre- and post-intervention labels. Data were collected using standardized case report forms, and all personnel involved in data collection and supervision underwent structured training to ensure competency and enhance measurement reliability.

The primary outcome was the change in perceived fatigue measured using the Borg RPE. Secondary outcomes included hemodynamic responses (HR and BP) and safety, defined as the absence of adverse events such as dizziness, syncope, chest pain, desaturation, or falls during the intervention. HR was monitored using a calibrated pulse oximeter, and BP was measured using an automated sphygmomanometer, following standardized hospital protocols. Two readings were obtained at each time point, and the mean value was used for analysis. Post-session measures were recorded immediately upon completion of the exergame.

Exergame intensity was determined using age-predicted maximum HR (HR_{max}; Fox formula: $220 - \text{age}$).^{13,14} The post-session HR was expressed as HR_{max} and categorized as light, moderate, or vigorous according to the American College of Sports Medicine guidelines: light (<64%), moderate (64–76%), or vigorous (77–95%). RPE scores were used as a subjective measure of perceived exertion and were similarly classified as light (≤11), moderate (12–13), or vigorous (≥14).¹⁵ Given the older patient population, potential attenuation of HR responses due to age-related factors or beta-blocker use was acknowledged. All outcomes were assessed by trained ward personnel using standardized case report forms to ensure measurement reliability.

Participant characteristics, including age, sex, comorbidity burden, cognitive function, and medical diagnosis, were recorded. Age was classified as young-elderly (60–69 years), mid-elderly (70–79 years), and old-elderly (≥80 years) according to the Indonesian

Central Bureau of Statistics.¹⁶ Morbidity was assessed using the Charlson Comorbidity Index (CCI), with scores >4 indicating high mortality risk according to a previous study.¹⁷ Potential confounders, such as cardioactive medication use (e.g., beta-blockers), baseline rhythm abnormalities, oxygen therapy, comorbidity burden, and cognitive status, were identified *a priori*, and descriptive stratification with planned sensitivity analyses was performed to assess their influence on exercise tolerance and HR response.

Data analysis

Statistical analyses were performed using SPSS software version 24 (IBM Corp., USA). Continuous variables were reported as means and standard deviations, and categorical variables as proportions. The normality of continuous variables was assessed using the Shapiro–Wilk test. For normally distributed variables, paired sample t-tests were used; linear regression was used to adjust for comorbidities, and the Wilcoxon signed-rank test was applied for non-normally distributed data. Results were reported with 95% confidence intervals (CIs). Missing data were addressed using listwise deletion. Prespecified subgroup and sensitivity analyses were conducted by age category, comorbidity burden, and use of cardioactive medication to evaluate the robustness of the findings.

RESULTS

A total of 32 patients were screened for eligibility using consecutive sampling. All patients met the inclusion criteria, agreed to participate, and completed the VRAGMENT intervention, resulting in no dropouts; thus, all 32 participants were included in the final analysis. The characteristics of the study participants are summarized in Table 1, with a median age of 66 years (range 60–85). Following the exergame session, mean HR increased significantly compared to baseline (82 [18] beats per minute [bpm] versus 79 [17] bpm; $p = 0.004$), with a significant mean difference (4 [8] bpm). SBP (−1 [14] mmHg) and DBP (0 [12] mmHg) decreased slightly, and the changes were not statistically significant ($p > 0.05$) (Table 2).

Regarding exercise intensity, most participants engaged in light-intensity activity, as assessed using both the Fox-predicted HRmax ($n = 19$, 59%) and RPE scales ($n = 27$, 84%). Only a minority reached moderate or vigorous intensity. Table 3 presents the distribution

Table 1. Subjects' characteristics

Variables	N = 32
Age (years), n (%)	
60–69	22 (69)
70–79	9 (28)
≥80	1 (3)
Male sex, n (%)	16 (50)
Education level, n (%)	
No formal education	1 (3)
Elementary school	8 (25)
Junior high school	9 (28)
Senior high school	10 (31)
University	4 (13)
CCI, n (%)	
Low (≤4)	11 (34)
High (>4)	21 (66)
MoCA-INA, mean (SD)	18.84 (6.3)
RPE score, median (min–max)	
Pre	6 (6–13)
Post	7.5 (6–15)

CCI=Charlson Comorbidity Index; MoCA-INA=Montreal Cognitive Assessment-Indonesian version; RPE=rating of perceived exertion; SD=standard deviation

MoCA-INA: score 0–30; RPE (Borg 6–20) categories

of the exergame intensity using both objective (HRmax-based) and subjective (RPE) assessments. No sentinel events were observed during or after the exergames.

Post-session HR remained within predefined safety limits, ranging from 53 to 125 bpm. Exercise intensity classification was based on percentage HRmax and RPE rather than raw HR values. The lowest HR in this study exceeded the lower safety limit (40 bpm), and the highest HR remained below the upper limit (130 bpm).

Given the high comorbidity burden among participants, further analysis was performed for this vulnerable condition. To identify key considerations when administering exergames to individuals with high comorbidity burden, we analyzed the correlation of vital sign response to exergames with CCI scores using linear regression analysis, as shown in Table 4. Only pre-exercise vital signs were significantly negatively correlated with CCI.

DISCUSSION

The primary outcome, HR, increased significantly after the exergame, consistent with an acute aerobic

Table 2. Changes in vital signs pre- and post-exergame

Variables	Pre, mean (SD)	Post, mean (SD)	Δ Mean (SD)	95% CI	p*
HR (bpm)	79 (17)	82 (18)	4 (8)	0.639–6.486	0.004
SBP (mmHg)	139 (18)	138 (21)	1 (14)	6.000–3.938	0.837
DBP (mmHg)	89 (14)	88 (16)	0 (12)	4.377–4.212	0.829

CI=confidence interval; DBP=diastolic blood pressure; HR=heart rate; SBP=systolic blood pressure; SD=standard deviation

*p-values from two-sided paired t-tests (Wilcoxon signed-rank if non-normal); Δ: post–pre; 95% CIs shown for mean differences

Table 3. Exercise-intensity classification during a single seated VR exergame session: RPE vs. %HRmax

Intensity level, n (%)	RPE, n (%)	Objective measurements	
		Fox equation, n (%HRmax)	Age-corrected Fox, n (%HRmax)
Light	27 (84)	26 (81)	19 (59)
Moderate	4 (13)	4 (13)	8 (25)
Vigorous	1 (3)	2 (6)	5 (166)

HRmax=age-predicted maximum heart rate; RPE=rating of perceived exertion; VR=virtual reality

%HRmax categories per American College of Sports Medicine (ACSM): light <64%, moderate 64–76%, vigorous 77–95%; RPE (Borg 6–20) categories: light ≤11, moderate 12–13, vigorous ≥14; recorded immediately post-session

response, whereas the secondary outcomes (SBP and DBP) showed small, non-significant changes within the predefined safety limits. This study demonstrated that a single session of VR-based exergaming significantly increased HR in older adults, indicating a physiological response consistent with acute aerobic exercise. An increase in HR is a key mechanism for enhancing cardiac output to meet the increased oxygen demand of muscle contraction during physical activity.¹⁸ In summary, the prespecified objectives were achieved: (1) cardiovascular response was confirmed by a small but significant increase in HR, consistent with acute aerobic engagement; (2) exercise intensity was classified as light-to-moderate based on percentage HRmax and RPE, indicating feasibility and safety in older adults; and (3) SBP and DBP remained stable, within ward-defined safety limits. No adverse effects were observed.

In contrast, a previous study using passive panoramic VR for relaxation therapy showed a decrease in HR from baseline following VR exposure (mean difference: 1.8, 95% CI: 0.6–3.0, $p<0.05$).¹⁹ This discrepancy likely reflects the differences in the interventions, as our study employed exergame-

based active VR designed to promote physical activity, increase metabolic demand, and trigger cardiovascular responses. To our knowledge, no prior studies have examined the application of active VR in acute inpatient settings. However, studies of exergames in older adults and rehabilitation patients have consistently reported cardiovascular activation, with increases in HR and perceived exertion, alongside good tolerability.^{20,21} Similarly, early mobilization studies in hospitalized and critically ill patients have demonstrated physiological activation (including HR and BP) while remaining feasible and safe.²² These findings suggest that our results align with the broader mobilization literature, while highlighting the novelty of applying active VR in an acute context.

HR is a key indicator of cardiovascular response and is widely used to determine exercise intensity and prescribe physical activity. Although cardiopulmonary exercise testing (CPET) with gas exchange analysis is the gold standard for measuring HRmax and exercise intensity,²³ it is often limited by cost, equipment availability, and procedural complexity. As a practical alternative, the Fox formula ($\text{HRmax} = 220 - \text{age}$) has been widely applied to older populations. Despite its limited agreement with CPET, it remains the most feasible option among the available equations.¹³

Nevertheless, differences between studies may not be attributable to the modality alone. Other potential contributors include variations in session duration or frequency, patient positioning (seated versus standing mobilization), the level of supervision and encouragement provided, and the use of chronotropic medications that can attenuate or augment HR responses. Age-related differences in cardiovascular adaptability and the methods used to prescribe or estimate exercise intensity (e.g., predicted HRmax equations or perceived exertion scales) may also influence outcomes. Considering these factors provides a more comprehensive

Table 4. Correlation of CCI with vital sign before and after a single exergame session

CCI	Pre-exergame			Post-exergame		
	r	p	95% CI	r	p	95% CI
HR (bpm)	0.370	0.037*	5.647–0.185	0.236	0.194	4.967–1.049
SBP (mmHg)	0.480	0.005*	6.577–1.249	0.197	0.280	5.297–1.588
DBP (mmHg)	0.549	0.001*	5.339–1.473	0.251	0.165	4.299–0.770

CI=confidence interval; CCI=Charlson Comorbidity Index; DBP=diastolic blood pressure; HR=heart rate; SBP=systolic blood pressure
Pre: immediately before session; post: immediately after session

explanation for discrepant findings and reinforces the strength of this study in demonstrating that active VR exergames can be safely implemented in an acute setting.

The Fox equation overestimates HRmax by approximately 12% (7.4–15.5 bpm) compared with CPET. Nevertheless, it remains useful under resource-limited or clinically constrained conditions when combined with appropriate precautions. These include professional supervision by personnel trained in emergency response, careful monitoring of both quantitative (HR and BP) and qualitative parameters (pallor and cyanosis),^{24,25} and careful review of medications such as beta-blockers, which can influence HR response and further contribute to HRmax overestimation.²⁵

In this study, exergaming was predominantly classified as a light-intensity activity based on both the Fox equation and the RPE scores, with only a small subset reaching moderate or vigorous intensity after correction. Despite these variations, no sentinel cardiopulmonary events occurred, supporting the safety of the exergame protocol in the acute geriatric setting. Baseline data indicated that the mean SBP among participants fell within the high-normal or prehypertensive range.²⁶ Following the exergame session, SBP decreased slightly, while DBP remained relatively unchanged. These findings align with those of previous studies that reported acute reductions in SBP following low-to-moderate-intensity aerobic exercise.^{27,28}

The mean SBP reduction observed in this study was higher than that reported by Lopes et al.²⁷ The magnitude of BP reduction is known to correlate with both exercise intensity and baseline BP, with individuals presenting with higher pre-exercise BP typically experiencing greater reductions.²² A proposed mechanism involves reduced baroreceptor sensitivity post-exercise, resulting in decreased

sympathetic nervous system outflow and subsequent vasodilation.²⁸ Although the BP changes observed were not statistically significant, the findings suggest a potential acute benefit of exergaming in BP control.

In this study, most of the participants had high CCI scores. However, no correlation was found between post-exergame vital signs and CCI, suggesting that comorbidity burden did not predispose patients to exaggerated cardiovascular responses. This finding indicates that exergames can be safely applied across patients with varying comorbidity profiles, supporting their feasibility in acute care settings. From an implementation perspective, the short session duration, minimal equipment requirements, and ease of supervision make active VR exergames practical for bedside mobilization, even in high-dependency wards. These findings are relevant for exercise prescriptions, as they reinforce the importance of tailoring intensity within safe hemodynamic thresholds rather than excluding high-risk patients solely based on comorbidity scores.

Moreover, the results can be interpreted within a behavior-change framework. Exergames provide an engaging platform that leverages motivation, enjoyment, and interactivity to promote adherence to mobilization and exercise regimens among vulnerable populations. By reducing psychological and physiological barriers, VR exergames may facilitate continuity from inpatient mobilization to post-discharge physical activity.

In terms of validity, this study demonstrated strong internal validity through standardized monitoring protocols, consistent supervision, and predefined safety criteria. Regarding external validity, the findings are applicable on two levels: first, to comparable hospitalized older adults where early mobilization is a clinical priority; and second, more broadly, to other acute care patient

populations who face barriers to traditional exercise modalities. These aspects underscore the feasibility and translational potential of VR exergames in clinical practice.

However, this study had a few limitations. First, studies on VR in clinical settings are limited, particularly in the geriatric population and acute wards; therefore, some references are over 5 years old. Despite this, the findings highlight the potential of VRAGMENT to encourage further development and innovation in VR-based interventions. Second, this study was not designed to compare VR and conventional physical activity, limiting the depth of exploration into the relative benefits of VR. This study only assessed a single exergame session; therefore, long-term effects are unknown. Third, all sessions were conducted at a single hospital, which limits generalizability. Although this study demonstrated that VRAGMENT is safe for use in acute wards, further studies should evaluate multiple sessions in a multicenter setting. Additionally, exergame intensity was not measured using gold-standard methods such as CPET with gas exchange analysis, which are impractical for bedside use in acute care owing to equipment limitations and practical challenges, including simultaneous use with VR headsets and vital sign monitors. Future development of portable, integrated CPET-VR systems would be beneficial for more precise assessment of exercise intensity.

In conclusion, a single session of VR-based exergaming significantly increased HR above baseline in older adults, indicating a physiological response consistent with exercise. Both objective (HR) and subjective (RPE) assessments classified the activity predominantly as light intensity. Future research should explore factors influencing exergame intensity to facilitate personalized exercise prescriptions.

Conflict of Interest

The authors affirm no conflict of interest in this study.

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